FEDERAL EXPERIMENT STATION IN PUERTO RICO

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

MAYAGÜEZ, PUERTO RICO

BULLETIN NO. 48

STUDIES OF FACTORS INFLUENCING ATTACK AND CONTROL OF THE BAMBOO POWDER-POST BEETLE

By

HAROLD K. PLANK, *Entomologist*

Issued August 1950

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH ADMINISTRATION
OFFICE OF EXPERIMENT STATIONS

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INTRODUCTION

Long and extensive use of bamboo in the Orient and other parts of the Old World has led to the introduction and establishment of many species in the Western Hemisphere. Perhaps the largest collection of tropical bamboos in this Hemisphere, assembled mostly during the past 15 years, is now growing at the Federal Experiment Station at Mayaguez. Early attempts to utilize bamboo soon revealed that the wood of the common local species, *Bambusa vulgaris* Schrad. ex Wendl., deteriorated rapidly. The chief cause was severe infestation by the bamboo powder-post beetle (*Dinoderus minutus* (F.)).[1] This

[1] Order Coleoptera, family Bostrichidae. Determined by W. S. Fisher, Bureau of Entomology and Plant Quarantine, Washington, D. C.

beetle is sometimes erroneously called "polilla" because of its habit of discharging powdered wood and excrement from its burrows in a way similar to that of the powder-post or dry-wood termites, *Kalotermes* (*Cryptotermes*) spp., which are known by the local or Spanish common name polilla.

As other introduced species of bamboo became available for trial, the beetle was found to attack them also, but in varying degrees of intensity. In some species nearly complete destruction followed in only a few months; in others it took place slowly, sometimes after the wood had already been employed in manufacture. So serious was the damage in both the stored and the fabricated wood of all but a few desirable species that it became evident that successful utilization and the development of a bamboo industry depended on the control of this pest.

The damage caused by the bamboo powder-post beetle is characteristic of many small beetles that bore into the harvested wood of a number of plants. The adults find attractive places for entrance at breaks in the rind of the culms, such as the cut ends and trimmed nodes. Once inside, they make many exploratory tunnels across the grain of the wood and deposit their eggs in the tubular vessels of the fibrovascular bundles thus cut. Feeding by the resulting larvae often reduces the infested piece to a mass of powdered wood and fibers.

A previous bulletin dealt with the distribution, habits, life history, and natural enemies of this pest (*15*).[2] This bulletin records studies that have been made of factors influencing the susceptibility of bamboo to attack and of measures for reducing or preventing damage.

PROCEDURE

In beginning these studies it was soon discovered that a standardized method of procedure was needed to minimize variations in results due to technique. Early laboratory tests (*20, p. 31*) employed strips cut from two culms of separate clumps to represent each treatment under study. These were randomized in galvanized sheet-iron cages that measured 15 inches wide and 16 inches high by 20 inches long and that were screened on the front, top, and back with 30-mesh copper-wire cloth. From 500 to 600 beetles collected from heavily infested bamboo wherever it could be found were liberated in each cage.

Cage Tests

In the tests reported here, five entire culms from separate, fully developed clumps were used for each treatment. The top was cut off at the ½-inch diameter, on the assumption that this is the smallest diameter of any piece that would be used commercially. Since some culms showed a gradient of susceptibility to the powder-post beetle (*20, pp. 32–34*), test pieces were taken from the basal, middle, and top internodes of each culm used, the middle internode being the one that was numerically in the middle. The day following harvest, eight test pieces in the form of ¾-inch rings were sawed from the internodes representing each of these three positions in the clum. After being

[2] Italic numbers in parentheses refer to Literature Cited, p. 38.

labeled for identification, one-half of the rings was randomized in one of the cages previously described and half in another, each species, treatment, clump, and position being equally represented in each cage. The rings were stood on edge and spaced about one-fourth inch apart in rows so that the beetles could have equal access to each. On the next day, i. e., the second day following harvest, six reared beetles per ring were liberated in each cage. The cages were kept closed for 1 month, and at the end of this time the number of attacks or entrance holes made by the beetles in each test piece was counted and used as the basis from which to compute the results of the test. Figure 1 shows the method of arranging the rings and of closing the cages.

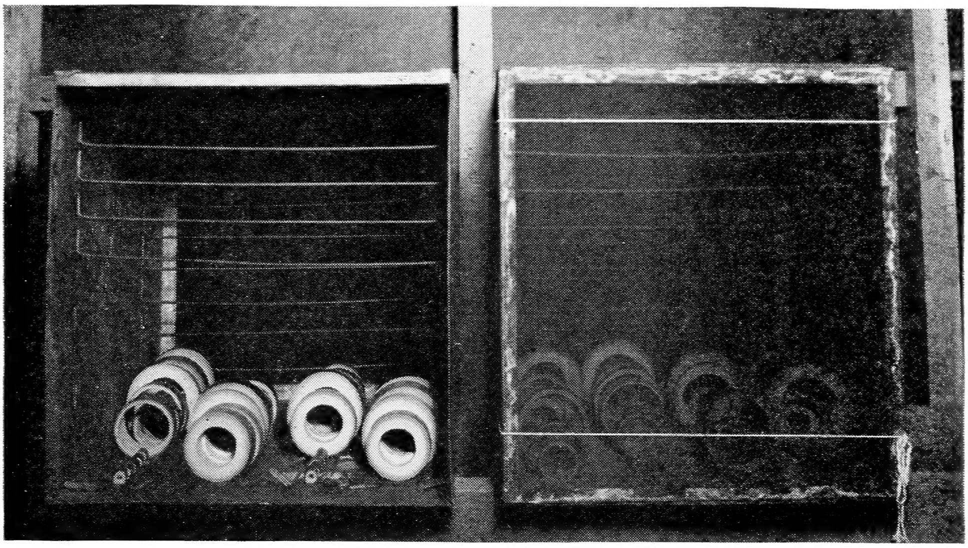

FIGURE 1.—Bamboo test pieces randomized in screened metal cages for testing susceptibility to attack by *Dinoderus minutus*. Cage at right is infested with beetles and closed. × 1/8.

REARING.—The use of reared beetles reduced to insignificance the variation between cages in the number of beetle attacks recorded. Advantage was taken of the habit of this insect under local conditions of breeding continuously in the presence of a suitable food supply (*15, p. 20*). Culms of *Bambusa vulgaris* in their first year of growth were freshly cut each month into lengths of one internode each to serve as the rearing medium. Some of the rind was peeled off at the same time to facilitate entrance of free-ovipositing beetles. These pieces were then stored in a breeding room as shown in figure 2. At the end of about 2 months a new brood of adults was ready to emerge and these were secured whenever needed by placing the infested pieces in large cans as shown in the figure. The emerging beetles left the bamboo in the fading sunlight of midafternoon and evening (*15, p. 18*). In trying to escape they passed through a small hole in the end of the wire-cloth cone cover and were caught in a bottle containing bamboo sawdust held over the end. Daily collections of the trapped beetles, usually 100 or more from each emergence cage at first, less later on, assured normal insects of known emergence date whenever desired.

Large-Scale Tests

For tests on a larger scale, whole culms were used from at least five separate clumps. The culms were trimmed as before and cut into two or three adjacent pieces containing equal numbers of internodes. After treatment these pieces were stored in an open shed away from rain and direct sunlight where beetles from nearby infested bamboo could have easy access to them. Parts of culms remaining after material for cage tests had been taken were also stored in this manner. At the end of several months, all such pieces were examined for evidences of beetle infestation. All internodes having one or more entrance holes that were deeper than the average length of the beetle (about 0.1 inch or 3 millimeters) were counted as infested. If entrances in a bud, branch-trimmed node, or bud-sheath scar penetrated more than ½ inch they were counted as infestations in the corresponding internode.

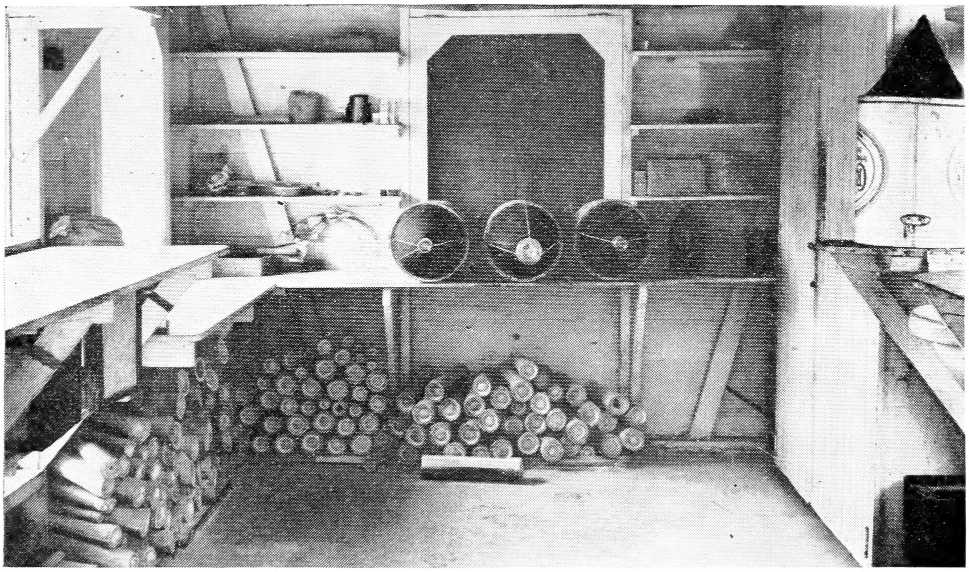

FIGURE 2.—Room employed for rearing *Dinoderus minutus* for use in tests. Freshly cut pieces of 1-year *Bambusa vulgaris* culms were used as the rearing medium.

External evidence of infestation was not always a dependable indication of the true condition of the culm. Sometimes beetles entering at one node would bore into both adjacent internodes or even several internodes without such boring becoming evident on the surface. Therefore, the culms were split open from end to end to determine the extent of attack from within as well as from without. Relative infestation determined in this manner usually corresponded closely with that found in the cage tests.

SUSCEPTIBILITY

One of the essentials in the utilization of any species of bamboo is some knowledge of its liability to attack by the powder-post beetle,

Dinoderus minutus. Susceptibility studies were, therefore, made of various species in the station planting as they became available. Exploratory tests indicated that with few exceptions *Bambusa vulgaris* was more heavily attacked than any other species (*21, pp. 29–30*). Since this species was also the most readily available in quantity and in a wide range of ages, it was used as the test species, or standard of comparison, in studies of susceptibility. On account of their greater susceptibility, the first-year culms were particularly well suited to studies of control.

Some of the factors found to influence the susceptibility of bamboo wood to attack by this insect are discussed in the following paragraphs.

Starch

Probably the most important factor predisposing bamboo to attack by the powder-post beetle is the presence of starch in the wood. The extent of destruction of any particular part of the culm depends largely on the distribution and concentration of this food material (*15, pp. 4–6*). This has been known for some time to be true of other woods infested by the closely related lyctid beetles (*Lyctus* spp.), which live on the starch of these woods (*6, p. 201*). Similarly, the adults of *Dinoderus minutus* digest the starch in the bamboo wood they consume while boring in a culm (*23, p. 82–83*); starch and perhaps other carbohydrates are necessary for the development of the resulting larva (*5, p. 6*).

Quantitative estimation

Quantitative estimations of starch in bamboo wood were made by means of the iodine spot test. A solution containing 0.3 gram of iodine and 1.5 grams of potassium iodide in 100 milliliters of water, such as that suggested by Johansen (*7, p. 188–189*), was tried, but gave too deep a stain to differentiate in many cases between starch-bearing and non-starch-bearing tissues. This difficulty was obviated by increasing the amount of water in the foregoing formula to 300 milliliters. Tests with this solution were made on the usual ring samples, one each from the base, middle, and top of every culm, at the time the corresponding test pieces were exposed to beetle infestation. Since the culms were harvested only 2 days previously, the wood was still moist. About a half-inch radial portion of the cross-section surface from the inside or center to the outside culm wall of the sample was shaved smooth with a clean, sharp knife to remove any particles of sawdust or other contaminating material that might tend to intensify or obscure the characteristic dark-blue color reaction of the iodine test.

IODINE-STARCH SCORE.—Between 2 and 5 minutes after the test solution was applied, the stained section was examined under a 10-× hand lens and an estimate made of the relative abundance of starch-bearing cells in the pithy tissue among the fibrovascular bundles. The range of abundance of such cells—from none to all in the area stained—was divided into eight arbitrary gradations to which were assigned numerical values, or score points, from 0 to 7, inclusive.

These gradations can be characterized approximately as follows:

0. *No color reaction.* No stained cells discernible.
1. *Very weak color reaction.* Few, about 1/16 or less, of the pith cells stained; only a trace of very light bluish-gray color discernible without hand lens.
2. *Weak.* About 1/8 of the pith cells stained; general appearance of section very light bluish gray.
3. *Moderately weak.* About 1/4 of the pith cells stained; general appearance, light bluish gray.
4. *Moderate.* About 1/2 of the pith cells stained; general appearance, bluish gray.
5. *Moderately strong.* About 3/4 of the pith cells stained; general appearance, blue.
6. *Strong.* Almost all, about 7/8, of the pith cells stained; general appearance, deep blue.
7. *Very strong.* All pith cells stained; general appearance, deep blue to black.

The total of the score points thus obtained on the three samples from each culm used was taken as the total iodine-starch score for any species, age, or treatment under study.

Correlation with infestation

Among the species tested there was a strong positive correlation between infestation and starch concentration, determined as described above. This was also true within most of these species, as will be seen in connection with discussions of the influence of other factors on infestation. It is of interest, for example, to point out that the heavily infested standard test species, *Bambusa vulgaris*, was found to contain more starch than any other bamboo tested and the coefficient of correlation between infestation and starch concentration was highly significant. In line with the known susceptibility gradient in culms of this species, the basal internodes usually contained more starch than the middle and upper internodes. However, an outstanding exception to this occurred in the young culms; here the basal internodes tended to have slightly less starch than the middle ones, but were still more heavily infested. Since differences in starch concentration in these young culms were not statistically significant, other conditions were undoubtedly responsible. This interrelation of starch and beetle infestation in different parts of culms of *B. vulgaris* from 1 to 5 years of age is shown graphically in figure 3.

Species and Varieties

The amount of damage caused by the bamboo powder-post beetle in various species of bamboo has already been referred to. Comparative studies revealed that it varied widely not only among species but also among varieties. In a preliminary test of 2-year-old culms, a dark-green, thick-walled variety of *Bambusa arundinacea* (of authors) was attacked only 4.7 percent as much as *B. vulgaris*, whereas a light-green, thin-walled variety of this species had a susceptibility of 250.6 percent, and a small-leafed, semisolid variety of *Dendrocalamus strictus* Nees 154.1 percent (*21, p. 32*).

In standardized cage tests, the susceptibility of the 1-year-old culms of 11 other species and varieties was obtained in comparison with culms of *Bambusa vulgaris* of the same age and date of harvest. The results of these tests are presented in table 1, along with the corresponding iodine-starch score at time of exposure to beetle infestation.

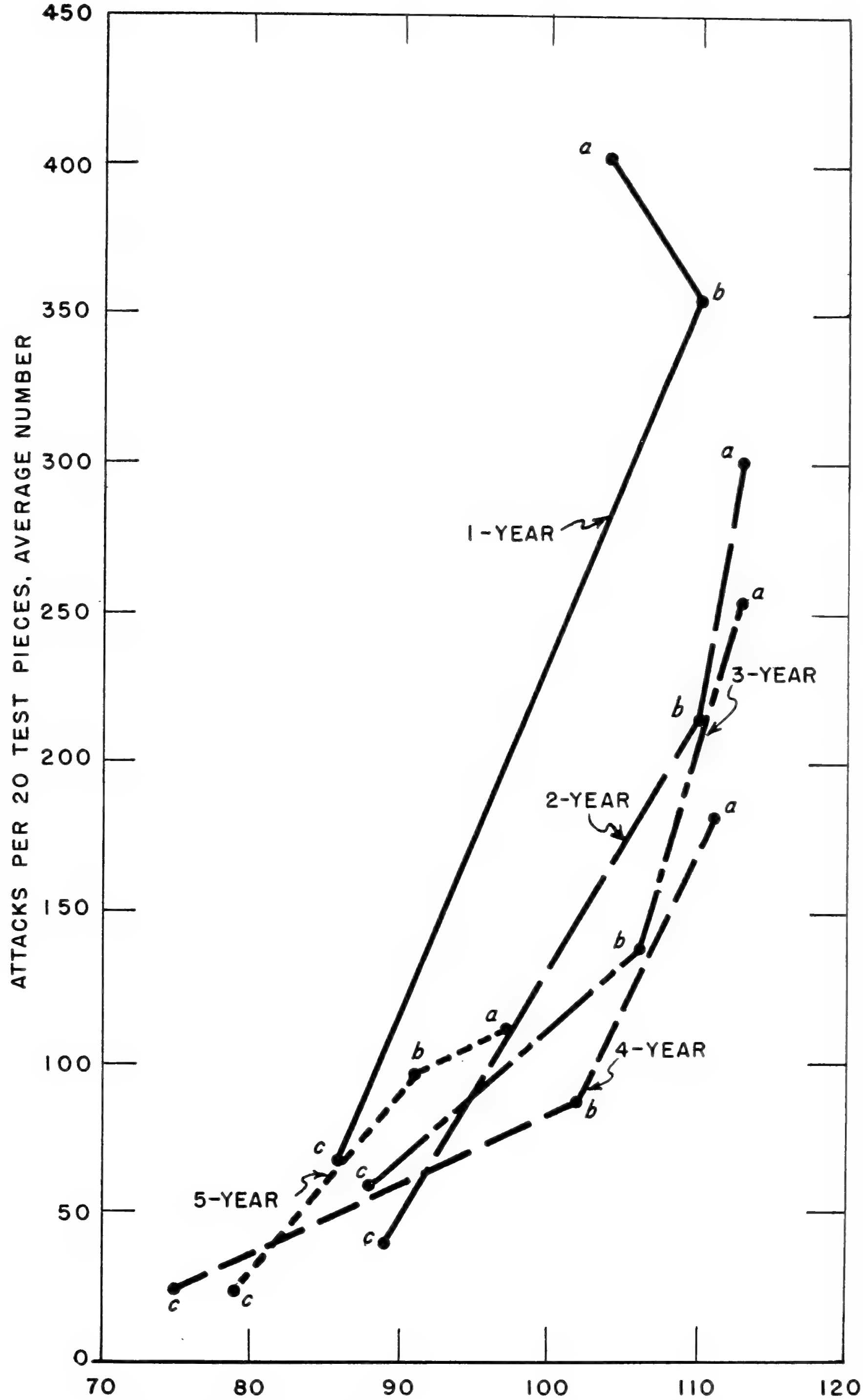

FIGURE 3.—Powder-post beetle attacks and starch concentration in wood of base (*a*), middle (*b*), and top (*c*) of culms of *Bambusa vulgaris* in their first 5 years of growth; average of five culms of each age from separate clumps in each of four harvests.

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TABLE 1.—*Susceptibility of 1-year-old culms of various species and varieties of bamboo to attack by the bamboo powder-post beetle compared with Bambusa vulgaris, and the corresponding iodine-starch score at time of exposure to infestation*

Species and variety	Susceptibility compared with *B. vulgaris* [1]	Iodine-starch score per 15 samples, average points [2]
	Percent	*Number*
Bambusa vulgaris Schrad. ex Wendl.[3]	100. 0	78. 7
B. vulgaris vittata A. & C. Riviere	44. 2	74. 0
B. polymorpha Munro	16. 8	64. 0
Dendrocalamus strictus Nees (large-leafed var.)	9. 6	18. 0
B. tuldoides Munro [4]	9. 0	37. 0
D. membranaceous Munro	9. 0	32. 0
D. giganteus Munro	6. 7	35. 0
B. longispiculata Gamble ex Brandis	6. 2	26. 0
B. tulda Roxb.[4]	4. 9	26. 5
B. tulda Roxb. var. (P. I. No. 74413)	2. 4	35. 0
Sinocalamus oldhami (Munro) McClure [4]	1. 5	18. 0
B. textilis McClure	. 3	12. 0

[1] Based on number of beetle attacks in equal numbers of test pieces from *B. vulgaris* culms of same age harvested at same time as species compared.
[2] Representing 3 positions in 5 culms from separate clumps per test.
[3] In 7 tests.
[4] In 2 tests.

It will be noted as shown in table 1 that, in comparison with the test species, *Bambusa vulgaris*, at 100 percent, the relative susceptibility of the 1-year-old culms of the other species varied from 0.3 percent in the thin-walled *B. textilis* to 44.2 percent in the striped *B. vulgaris vittata*. Besides *B. textilis*, a number of other commercially promising species showed only slight susceptibility, particularly both varieties of *B. tulda*, *B. tuldoides*, and a large-leafed variety of *Dendrocalamus strictus*. Not shown in table 1 is the fact that in all the species, except *D. membranaceous*, the top was the least susceptible part of the culm, and that in seven of the species the middle was less susceptible than the base. However, in *B. polymorpha*, *B. vulgaris vittata*, *D. giganteus*, *D. strictus*, and *Sinocalamus oldhami* the middle was more susceptible than the base but without statistical significance in *D. strictus* and *S. oldhami* (*10, p. 21; 11, p. 22*).

In stored whole culms of the highly susceptible species, such as *Bambusa vulgaris*, *B. vulgaris vittata*, and *B. polymorpha*, the beetles burrowed through most of the culm wall except the rind, preferring the softer portions near the inside where the tissues were richer in starch; in the less susceptible, they confined their attacks almost exclusively to the innermost part of the culm wall. In *B. longispiculata* and *Sinocalamus oldhami*, for example, the beetles scored furrows in the inside surface of approximately three-fourths of the internodes.

In *Dendrocalamus membranaceous* they bored directly into the rind at places where the culms were in contact with the drying rack or each other.

Starch Concentration.—Table 1 shows that there is a striking difference among the species with respect to concentration of starch and a strong positive correlation between this and susceptibility to beetle attack. Species with the highest susceptibility ratings consistently had high concentrations of starch in the wood at time of exposure to infestation. On the other hand, those of low susceptibility had much lower starch concentrations in proportion. Such irregularaties are explained partly by variations in the test species at time of harvest and partly by the operation of other factors, such as physical properties of the wood.

Starch Distribution.—The distribution of starch in the different parts of the 1-year-old culms tested followed the general pattern previously referred to. The usual tendency in first-year *Bambusa vulgaris* for the middle part to be richer in starch than the base, as shown in figure 3, was also found in *B. longispiculata*, *B. polymorpha*, *B. vulgaris vittata*, *Dendrocalamus giganteus*, *D. strictus*, and *Sinocalamus oldhami*. In *D. membranaceous* the top of the culm was found to contain more starch than either the middle or base. In general, the number of beetle attacks corresponded with this distribution in all but *B. longispiculata*, and in this species differences in number of attacks were not statistically significant.

Age at Harvest

The age at which bamboo is harvested has long been thought to influence its susceptibility to attack by the powder-post beetle. This assumption was confirmed by an early orientation test which showed that there was a difference of 37 percent in the number of beetle attacks between the two different ages of *Bambusa vulgaris*.

Documentation.—In some species the age of a given culm up to 3 years can be judged with a fair degree of accuracy from its general appearance and the condition of the bud-sheath remnants about the base. In other species these indications tend to become lost earlier. In order to have a supply of culms of known age from various species for study, culms were marked with the number of the year in which they sprouted. Since it was found that most species ordinarily finished sprouting by December, such dating was carried out in January and February. By this time, culms of the previous year had matured but were still readily distinguishable from older culms by their cleaner and brighter appearance. Marking with india ink proved unsatisfactory since it soon became obliterated by accumulations of dust and lichens. Therefore, the year of sprouting was etched into the rind of the culm with a nail or other stylus. Such marks have remained legible for 6 to 8 years and have been easily found when placed at a predetermined location, such as immediately beneath a node at about 4 feet from the ground and on the part of the culm perimeter nearest the outside of the clump.

A complete series of documented culms were tested from four commercially promising species, *Bambusa tulda*, *B. tuldoides*, a large-leafed variety of *Dendrocalamus strictus*, and *Sinocalamus oldhami*.

As normal culms of five consecutive years' growth became available it at least five clumps of a species, these culms were tested with corresponding culms of *B. vulgaris* harvested at the same time. The relative susceptibility at different ages—from 1 to 5 years—of each of these species, is shown in table 2.

TABLE 2.—*Susceptibility to powder-post beetle attack of culms of 4 species of bamboo in their first 5 years of growth, compared with culms of Bambusa vulgaris of corresponding age and date of harvest*

Species	Approximate age of culms in years				
	1	2	3	4	5
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Bambusa vulgaris	100. 0	100. 0	100. 0	100. 0	100. 0
B. tulda	[1] 4. 9	6. 9	19. 9	27. 3	18. 5
B. tuldoides	[1] 9. 0	10. 3	31. 6	30. 6	20. 5
Dendrocalamus strictus	9. 6	21. 1	15. 1	25. 7	26. 2
Sinocalamus oldhami	[1] 1. 5	1. 9	1. 2	17. 6	59. 0

[1] Weighted average of two tests.

It will be noted from table 2 that the culms of all ages of these species except the fifth year of *Sinocalamus oldhami* were less than half as susceptible as the test species, *Bambusa vulgaris*, at the same age. Likewise, comparisons within species show that the older culms of most are more susceptible than the first-year culms. However, some of these older culms were attacked less, and hence, would be considered less susceptible, than the younger culms of the same species. Important characteristics of these species with respect both to beetle attack and starch concentration are shown graphically in figure 4 and are discussed as follows:

BAMBUSA TULDA.—It is evident from figure 4 that *B. tulda* was attacked little at the ages tested. It was also uniformly low in starch. With some irregularity in the third and fourth years' growth there was a tendency for beetle attack to decrease with increase in age, although this tendency was not so strong as that already noted in *B. vulgaris*. However, only in the second- and fifth-year culms was the decrease sufficiently great to be significant (*13, p. 43*).

BAMBUSA TULDOIDES.—This species was attacked somewhat more severely than *B. tulda* and contained a much higher concentration of starch in the wood. As with the test species and *B. tulda*, there was also a general tendency for beetle attack to decrease with age, but the difference in attack between any two of the second-, third-, fourth-, and fifth-year growths was not statistically significant (*14, pp. 35–36*).

DENDROCALAMUS STRICTUS.—The large-leafed variety of *D. strictus*, relatively low in starch, showed a reversal of the tendency pointed out with previous species; the growth of the first, second, and third years was attacked to a lesser extent than the growth of the fourth and fifth years. The difference in beetle attack between any 2 years, however,

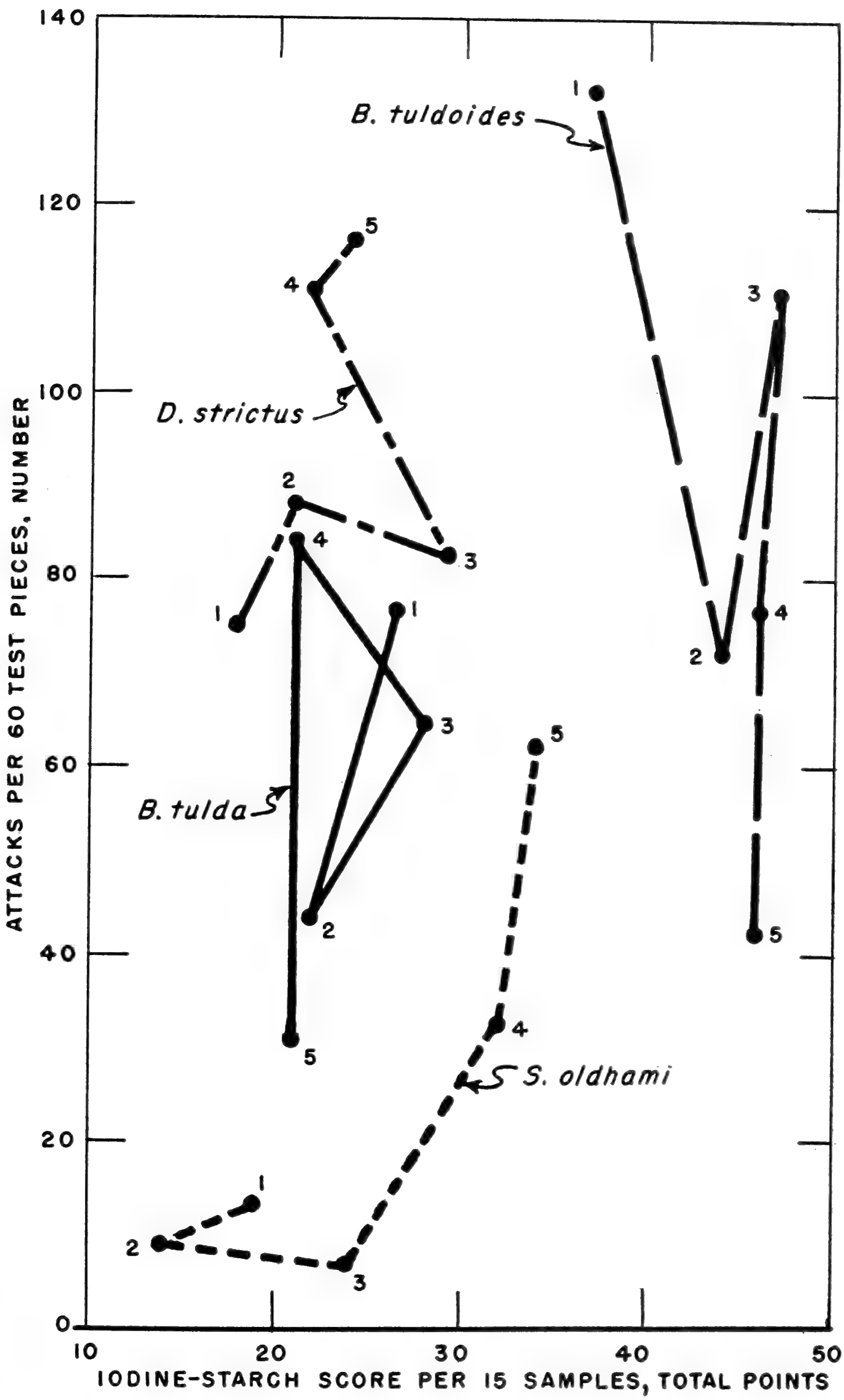

FIGURE 4.—Powder-post beetle attacks and starch concentration in culms of *Bambusa tulda, B. tuldoides, Dendrocalamus strictus*, large-leafed var., and *Sinocalamus oldhami* in their first 5 years of growth, as based on 5 culms of each species and age harvested from separate clumps. Numbers at points on graphs indicate growth year of culms.

was not sufficiently great to be statistically significant, and therefore all culms at the ages here tested may be of equal susceptibility.

Sinocalamus oldhami.—The same trend noted in *Dendrocalamus strictus* is shown even more clearly by *S. oldhami*. Culms of all five ages of this species were attached much less and contained much less starch than the corresponding culms of *Bambusa vulgaris*, the first 3 years' growth being comparatively immune and free of starch. Unlike any of the other species, the fourth- and fifth-year culms were attacked from three to six times more than the first, but the number of attacks in any one year's growth was too small for any of the differences among ages to be significant (*18, pp. 64–65*).

As with *Bambusa vulgaris*, there was a tendency in *B. tulda* and *B. tuldoides* for the base of the culms to be attacked more than the middle and the middle more than the top. In all the tested ages but the second of *Dendrocalamus strictus* and the fourth of *Sinocalamus oldhami*, the middle internodes were attacked more than the base, and the top little or scarcely at all. However, only in the fourth and fifth years of *D. strictus* was the difference in the number of beetle attacks sufficiently large to show any significance.

Starch Distribution.—In five ages of the species of *Bambusa* here considered, starch was distributed in a manner approximating that already noted for the 1-year-old culms (page 9). In *Dendrocalamus strictus* and *Sinocalamus oldhami*, however, the top parts of the culms usually contained the most starch but were still attacked the least; in these cases, as in the reverse condition found in the base of first-year culms of *B. vulgaris*, other factors than starch concentration influenced infestation.

In the foregoing tests it was evident that culms of the species of *Bambusa* examined had these characteristics in common—they showed relatively high infestation and starch content during their first and second years of growth and low infestation and low starch content during later years; whereas the species of *Dendrocalamus* and *Sinocalamus* tended to have characteristics directly opposite to these—low infestation and low starch content in the young culms and somewhat higher infestation and starch content in older culms. It would, therefore, appear that much of the damage caused by the bambo powder-post beetle can be avoided in *B. vulgaris* by harvesting culms 3 years old or older, and in *B. tulda* and *B. tuldoides* by harvesting those 2 years old or older. To minimize attack in the large-leafed variety of *D. strictus* and in *S. oldhami*, the culms should be harvested during their first 3 years of growth. For certain uses, artificial control will be necessary to reduce infestation further.

Time of Harvest

Season of year

As with other woods, the season or time of the year when bamboo is harvested has been supposed to influence its susceptibility to attack by insects. Indications that such might be the case were obtained in cage tests of first-year *Bambusa vulgaris* culms harvested at various times over different years and subjected to attack by *Dinoderus minutus*. Seasonal variations in the susceptibility of culms of other ages or of other species were not investigated.

When the harvests were grouped according to the four seasons of the year, there were more beetle attacks in culms harvested in the winter and spring than in those harvested in the summer and autumn, but the number of examinations in any given season was too small for seasonal differences to approach significance. However, when the harvests were grouped according to half-yearly periods, the difference in infestation was more apparent and that in plant growth was pronounced. Four harvests were made during the late winter and spring months of February to May and three during the late summer and autumn months of August to December. The beetle attacks recorded on equal numbers of test pieces by harvests during these two periods, as well as corresponding data on starch concentration, length of day, and weather conditions, are summarized in table 3.

TABLE 3.—*Powder-post beetle infestation in 1-year-old culms of Bambusa vulgaris harvested at various times during 2 periods of the year at Mayaguez, P. R.*

Date of harvest	Beetle attacks [1]	Iodine-starch score, points [2]	Day length [3]	Mean temperature [4]	Monthly rainfall [4]
LATE WINTER AND SPRING PERIOD					
	Number	*Number*	*Hours*	*° F.*	*Inches*
Feb. 7 to Mar. 6, 1944	1, 129. 0	78	11. 7	76. 2	1. 56
Feb. 27 to Apr. 18, 1940	749. 0	80	12. 1	75. 9	2. 17
Apr. 26 to May 22, 1945	856. 0	71	12. 9	75. 2	11. 02
Apr. 28 to May 26, 1941	1, 790. 5	86	13. 0	78. 9	7. 76
Weighted average	1, 177. 3	78. 8	12. 4	76. 5	5. 24
LATE SUMMER AND AUTUMN PERIOD					
Aug. 9 to Sept. 7, 1948	785. 0	72	12. 6	80. 2	9. 72
Nov. 2 to Dec. 15, 1942	923. 5	85	11. 2	79. 6	10. 20
Dec. 2 to 18, 1946	532. 0	79	11. 1	77. 2	7. 99
Weighted average	791. 0	78. 7	11. 6	79. 3	9. 56

[1] Weighted average per 60 test pieces representing 3 positions in 5 culms from separate clumps.

[2] Total score points per 15 samples representing foregoing culm positions.

[3] Average per 10-day interval during harvest.

[4] Average for period beginning and ending 1 month previous to inclusive harvest dates.

The tendency for infestation to be high in the late winter and spring is plainly shown in table 3. The concentration of starch in the wood was apparently not appreciably affected by the time of harvest of the culms, or if it was, the iodine-spot test method used to determine it was not sensitive enough to reveal any great difference; the average score for the late winter and spring period was 78.8 while that for the

late summer and autumn period was 78.7, with no statistical significance between periods.

During the late winter and spring harvest period when infestation was high the length of time between sunrise and sunset increased (absolute range 11.5 to 13.1 hours) and there was a slight rise in mean temperature and an increase in monthly rainfall preceding harvest. During this period culms already full grown were beginning to send out new leaves, and some new culms had begun to sprout and appear above ground. On the other hand, during the late summer and autumn period when infestation was comparatively low, the average length of day was decreasing (absolute range 12.8 to 11 hours). The mean temperature and average monthly rainfall preceding harvest, although in general still higher than in the former period, showed a tendency to decrease also. During this latter period the culms were growing little or approaching, if not actually in, a dormant condition.

This concurrent decrease in day length, temperature, and rainfall at the time the late summer and autumn harvests were made no doubt so affected the physiology of the plants as to make the culms less attractive to the beetle. The same factors may also have had some effect on the physiology and activity of the insects. However, the harvests were too few in number and too discontinuous for the difference in beetle attack to be statistically significant at the 5-percent level. Nevertheless, the available data indicate that there is a close relationship between the results obtained here and those obtained with other species of bamboo in some parts of India (*3, p. 172; 5, p. 7*). Although not conclusive, there is some evidence that harvesting in the late summer and autumn tends to reduce infestation by the bamboo powder-post beetle.[3]

Phase of moon

The reason frequently given in the Tropics for infestation of wood by insects in that the tree from which it came was felled during the increase of the moon. The comparison is seemingly rather forcibly illustrated in some parts of the American Tropics. With some species there frequently appear to be sufficiently marked difference in infestation during specific phases of the moon to foster the belief that this factor is one not to be discarded lightly. For this reason some commercial timber and much of that harvested by individuals in the Tropics is cut during the decrease of the moon.

By extension, this custom is commonly applied to bamboo. In some localities in India, harvesting according to the phase of the moon is reported to be advantageous, although experiments conducted at Dehra Dun have failed to reveal any connection between moon phase and insect attack (*3, p. 173*).

The culms of *Bambusa vulgaris* used in the present studies were harvested by clumps at intervals of from 3 to 7 days. This permitted the classification of the subsequent beetle infestation according to the

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[3] Since this was written, another harvest, similar to those just discussed, was made in the "late summer and autumn period." When the data obtained in this harvest were included with those summarized in table 3, the figure for the average number of beetle attacks was lowered to 720 and that for starch score to 76 points. Although neither was statistically significant, they tend to emphasize the advantage of harvesting during this period.

phase of the moon at time of harvest. Culms harvested when the moon was increasing from "new" up to "full" were listed as harvested in the increase of the moon; those during the remainder of the lunar month, as harvested in the decrease of the moon. The number of beetle attacks thus recorded in 7 harvests of 1-year-old culms carried out over a period of 8 years is summarized in table 4, with the corresponding iodine-starch score.

TABLE 4.—*Powder-post beetle attacks and starch concentration in 1-year-old culms of Bambusa vulgaris harvested during the "increase" and "decrease" of the moon at Mayaguez, P. R.*

Month and year of harvest	Phase of moon					
	Increase [1]			Decrease [2]		
	Clumps harvested	Beetle attacks [3]	Iodine-starch score, points[4]	Clumps harvested	Beetle attacks [3]	Iodine-starch score, points
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
February–April, 1940	1	84. 5	20	4	664. 5	60
April–May, 1941	3	1, 373. 0	53	2	417. 5	33
November–December, 1942	3	580. 5	52	2	343. 0	33
February–March, 1944	3	678. 0	46	2	451. 0	32
April–May, 1945	3	304. 0	43	2	552. 0	28
December 1946	1	63. 0	12	4	469. 0	67
August–September, 1948	3	477. 0	42	2	308. 0	30
Total	17	3, 560. 0	268	18	3, 205. 0	283
Weighted average per clump	------	209. 4	15. 8	------	178. 1	15. 7

[1] From "new" to, but not including, "full."
[2] From "full" to, but not including, "new."
[3] Per total of 12 test pieces from base, middle, and top of 1 culm from each clump.
[4] Total score points per 3 samples representing foregoing culm positions.

In table 4 there is apparently shown a slightly greater infestation in the culms harvested during the increase than in the decrease of the moon. The average number of beetle attacks in the test pieces from 17 clumps of the former period was 209, and that from 18 clumps of the latter period was 178. According to the previously described method of sampling and testing, there was little difference in starch concentration between the two phases. For causes that could not be determined, there was also much variation in both beetle attack and starch concentration among harvests; differences in these characteristics as a result of different phases of the moon were not statistically significant. It is recognized that such factors as temperature and humidity conditions during the time the test pieces were exposed to

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the beetles, may have influenced the number of attacks recorded. Perhaps if more harvests or data from studies with bamboo of a greater diversity of ages and species were obtained, the trend toward lower average infestation during the decrease of the moon would be more pronounced. Under the conditions of the tests here reported, there is insufficient evidence to justify the belief that either phase of the moon is better than the other for harvesting bamboo to avoid powder-post beetle damage.[4]

Physical Properties of the Wood

The possibility that factors other than starch, particularly the physical properties of the wood, might influence powder-post beetle infestation in bamboo has already been referred to. Early studies of 1-year-old culms of *Bambusa vulgaris* showed a tendency for high moisture content to favor infestation (*23, p. 81*). Lack of infestation in certain other species that could not be accounted for by variations in starch and moisture content indicated that density of the wood, as measured by specific gravity, might be another factor. A sample of the usual size from each of the three positions in the culms tested was, therefore, set aside for the measurement of these two properties and the investigation of their influence on infestation. Apparatus was not available for the study of other physical properties, such as porosity and surface hardness.

When the corresponding test pieces were exposed to the beetle in cages, each sample was weighed and its volume displacement determined by submersion in distilled water, after the method used by Markwardt and Wilson (*8, pp. 7–8, 83*). Dipping in kerosene before submersion was employed to close the pores of the wood and to reduce to a minimum the possible leaching of any water-soluble material present. The samples were then oven-dried to constant weight of 100° C. As is customary in wood technology, the percentage difference, based on the oven-dry weight, was taken as the moisture content of the wood at time of exposure, and the ratio of the oven-dry weight to the original-volume displacement was used as the specific gravity.

1-year-old culms

Determinations of moisture and specific gravity of 1-year-old culms of the species listed in table 1 are summarized with the corresponding numbers of beetle attacks in table 5.

It is evident from the data given in table 5 that, except on the basis of species grouped according to moisture content, there was little correlation among the first-year culms between moisture content of the wood and infestation. However, not shown in table 5 is the fact that there was a consistent increase in the number of beetle attacks with each increase in moisture content among the different culm parts of eight of the species individually, and that in four of these, *Bambua longispiculata*, *B. vulgaris*, *B. tuldoides*, and *Sinocalamus oldhami*,

[4] This conclusion was strengthened by figures from an additional harvest made after the foregoing statement was written. When these statistics were combined with the results summarized in table 4, the resulting difference in infestation was even less pronounced—187.9 attacks for "increase" and 172.2 for "decrease" as averages of 20 clumps harvested in each phase.

the correlation coefficient was at least significant. Moisture was negatively correlated with infestation in *Dendrocalamus membranaceous*, *D. strictus* (large-leafed var.), *B. polymorpha*, and *S. oldhami*, but significantly so only in *D. membranaceous.*

TABLE 5.—*Moisture content and specific gravity of wood in 1-year-old culms of various species and varieties of bamboo at time of exposure to infestation, with corresponding number of powder-post beetle attacks*

Species and variety	Physical property of wood		Beetle attacks per 60 test pieces [2]
	Moisture content average [1]	Specific gravity average [1]	
	Percent		*Number*
Bambusa textilis	53. 6	0. 727	2. 5
B. longispiculata	68. 4	. 675	57. 5
Dendrocalamus membranaceous	76. 4	. 634	83. 0
B. vulgaris vittata	77. 8	. 626	408. 0
B. vulgaris [3]	79. 5	. 615	1, 174. 8
B. tulda [4]	80. 4	. 634	76. 3
D. strictus (large-leafed var.)	83. 1	. 608	75. 0
B. tuldoides [4]	85. 7	. 586	123. 3
B. polymorpha	88. 3	. 588	300. 0
B. tulda var. (P. I. 74413)	95. 1	. 557	42. 0
Sinocalamus oldhami [4]	102. 9	. 528	12. 0
D. giganteus	123. 2	. 463	119. 5

[1] Weighted average of 15 samples representing base, middle, and top parts of 5 culms from separate clumps per test. Since, as is customary in wood technology, moisture content is expressed as a percentage of the weight of the oven-dry wood, it is possible, as in the last two species in this table, for this percentage to be 100 or greater (*8, p. 7*).
[2] Representing equally all parts mentioned in footnote 1.
[3] In 4 tests, in which most of the other species were also represented.
[4] In 2 tests.

Among species, low specific gravity was somewhat more closely associated with beetle attack than was moisture, but only on the same group basis mentioned above. Individually, however, low specific gravity was correlated with infestation in eight species, the coefficient being significant in *Bambusa textilis*, *B. longispiculata*, *B. tuldoides*, and *Sinocalamus oldhami*. The reverse occurred in *B. tulda*, *Dendrocalamus strictus*, *B. polymorpha*, and *D. giganteus*, but without significance in any.

Culms of different ages

Studies were made of the association of moisture and specific gravity with infestation in 1- to 5-year-old culms of the five species of bamboo shown in table 2. Data from the first-year culms of these species are given in table 5, and these data are included in table 6 for comparison with data from the older culms.

TABLE 6.—*Moisture content and specific gravity of wood in culms of 5 species of bamboo in their first 5 years of growth at time of exposure to infestation, with corresponding number of powder-post beetle attacks*

Species	Approximate age of culms	Physical property of wood: Moisture content average [1]	Physical property of wood: Specific gravity, average [1]	Beetle attacks per 60 test pieces [2]
	Years	*Percent*		*Number*
Bambusa vulgaris [3]	1	79. 5	0. 615	1, 174. 8
Do.[4]	2	65. 4	. 672	668. 0
Do.[4]	3	52. 6	. 743	337. 0
Do.[4]	4	54. 7	. 725	280. 0
Do.[4]	5	56. 5	. 715	189. 0
B. tulda [4]	1	80. 4	. 634	76. 3
Do	2	60. 5	. 702	44. 0
Do	3	56. 5	. 725	65. 0
Do	4	51. 2	. 755	84. 0
Do	5	46. 8	. 778	31. 0
B. tuldoides [4]	1	85. 7	. 586	132. 3
Do	2	62. 0	. 688	72. 0
Do	3	55. 4	. 726	110. 0
Do	4	53. 0	. 743	77. 0
Do	5	52. 1	. 736	43. 0
Dendrocalamus strictus (large-leaf var.)	1	83. 1	. 608	75. 0
Do	2	69. 8	. 671	88. 0
Do	3	68. 0	. 677	83. 0
Do	4	77. 8	. 628	111. 0
Do	5	72. 2	. 649	116. 0
Sinocalamus oldhami [4]	1	102. 9	. 528	12. 0
Do	2	94. 0	. 547	9. 0
Do	3	83. 6	. 585	7. 0
Do	4	88. 7	. 569	33. 0
Do	5	75. 0	. 621	62. 0

[1] Weighted average of 15 samples representing base, middle, and top parts of 5 culms of each age from separate clumps per test, based on oven-dry condition.
[2] Equally representing all parts and culms mentioned in footnote 1.
[3] In 4 tests.
[4] In 2 tests.

As in first-year culms, little if any correlation between either moisture content or specific gravity of the wood and subsequent powder-post beetle infestation is apparent at any given age of the species shown in table 6. However, with a few individual exceptions, beetle attacks decreased in number with decrease in moisture content in culms of successive ages in *Bambusa vulgaris*, *B. tulda*, and *B. tuldoides*. Also with a few exceptions, the reverse was true in *Dendrocalamus strictus* and *Sinocalamus oldhami*.

In culms over 1 year old, the association of infestation was much less pronounced with specific gravity than with moisture content. No consistent decrease in infestation with increase in specific gravity is apparent, regardless of age, in any of the species summarized in table 6.

Correlation of these two physical properties—moisture content and specific gravity—with infestation in these species was influenced a great deal by the distribution and concentration of starch throughout the culm. Where moisture was significantly accompanied by infestation the culm parts containing the most moisture also contained the most starch. Likewise, in those species in which low specific gravity was significantly correlated with infestation, the parts having the lowest density were relatively high in starch. In other words, infestation was governed more by starch concentration than by either moisture content or specific gravity of the wood at time of harvest (*12, p. 33*).

PREVENTIVE MEASURES

As suggested in the foregoing section, much can be done indirectly to reduce the damage caused by the bamboo powder-post beetle by planting species and varieties known to be resistant and by harvesting culms at their most resistant ages. Also, the prompt burning of all waste pieces of bamboo and of others as soon as attacked will greatly reduce the beetle population by destroying breeding places and thus reduce the danger of infestation in wood that is curing or in the process of manufacture. With no other treatment than careful inspection during storage and the destruction of infested pieces, a few of the bamboo species thus far investigated have given satisfactory service over a number of years with little if any further damage. However, loss by culling on account of the beetle in some species, like *Bambusa tuldoides*, has averaged about 25 percent and occasionally has been as high as 50 percent of the culms harvested. Studies of the direct measures by which these losses may be reduced or prevented are summarized here.

Curing or Seasoning

Among the oldest methods used to restrict damage by this insect is that of curing or seasoning the wood. This has usually been accomplished either by drying the culms or immersing them in water immediately after harvest. The effects of both air drying and water curing have been to reduce the starch content and to bring about physical changes that tend to make the wood less liable to infestation.

Air drying

It has frequently been observed that after the first flush of infestation in freshly harvested culms has subsided, usually in about 8 weeks, little further attack will be made on the parts remaining (*21, pp. 31–32*). Although the starch concentration is reduced, sufficient may still remain to produce a moderately strong reaction to iodine. Drying and the accompanying increase in density of the wood apparently account for much of the increase in resistance. Where it is possible to keep the culms from becoming infested during this period, drying or air seasoning has definitely reduced susceptibility to attack.

Some of the beneficial effects of drying were shown in an experiment in which sample rings from the middle internodes of freshly harvested 1-year culms of *Bambusa vulgaris* were protected from the beetle in screened cages while air-drying for ½, 1½, 3, and 6 months. The number of attacks during 1 month of subsequent exposure tended to decrease as the drying time increased. In the bamboo that had air-

dried for 6 months before exposure there were 83 percent less beetle attacks than in that air-dried for ½ month, a difference that was statistically significant (*16, p. 65*).

Clump Curing.—Application of the drying principle to felled culms in the field, where beetle infestation has rarely been observed, has resulted in up to 90 percent control by what has been called clump curing (*22 pp. 115–116*). The untrimmed culms were maintained upright in the clump where cut and allowed to dry in this position for about a month (fig. 5). Other arrangements for accomplishing

Figure 5.—Clump-curing bamboo culms in the field to reduce subsequent damage by the bamboo powder-post beetle.

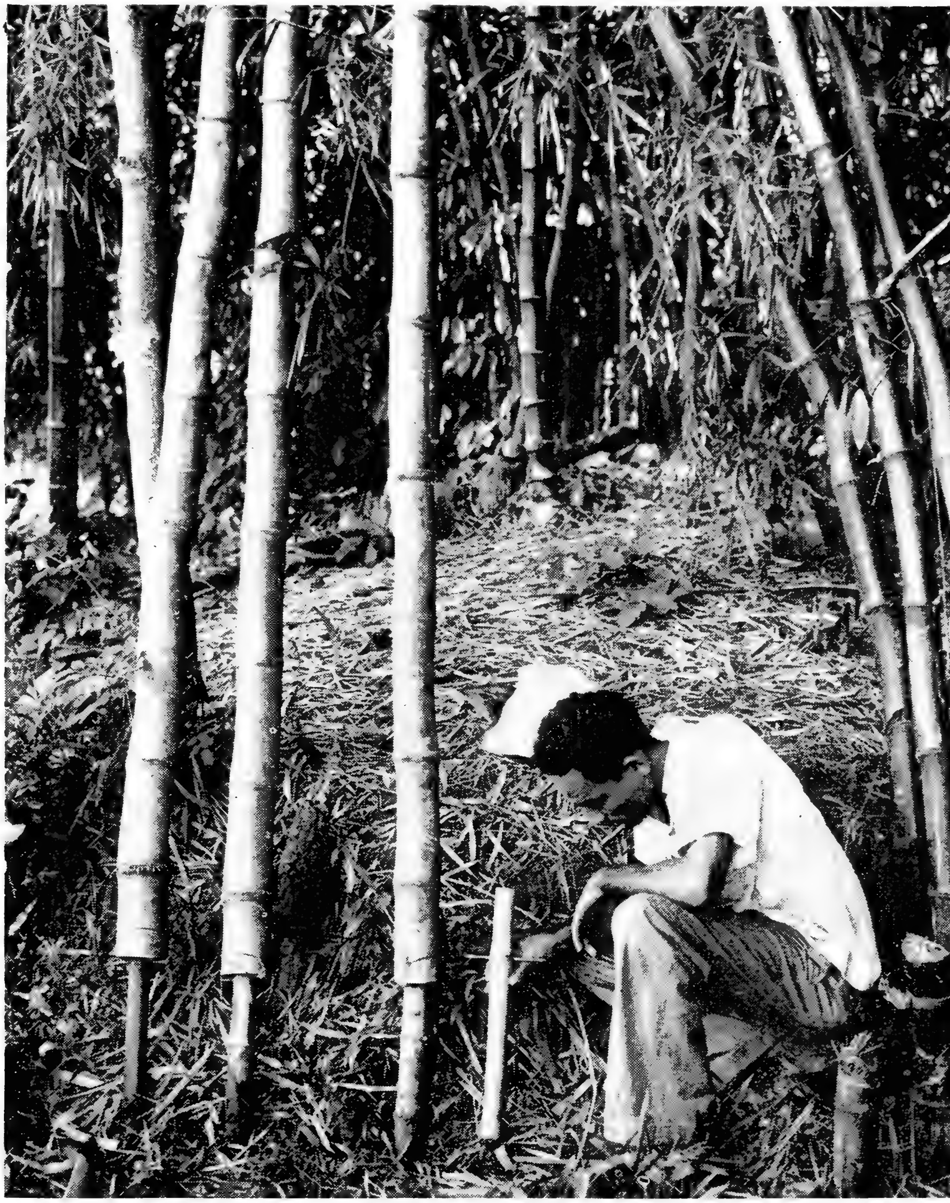

FIGURE 6.—Prop inserted in the base of upright culms to prevent contact with the ground during clump-curing. A heavy nail through the end of the prop prevented breaking the septum and splitting the basal internode.

the same purpose have been used, but best results and comparative freedom from sap stain were obtained when the leaves and branches were kept open and the base of the culm did not come in contact with the ground. One method that has proved satisfactory for a small number of culms is shown in figure 6.

The effect of clump curing on infestation and starch was well illustrated in experiments with *Bambusa vulgaris* culms in their first year of growth. Clump curing has been practiced on other species with essentially the same results.

Uniform sets of culms were selected in each of a number of clumps. When the clump-cured sets were trimmed and tested the check or control sets were harvested green and immediately tested along with them. Table 7 sumarizes the data on infestation and starch concentration obtained from culms harvested from five clumps in each of 2 years under what are characterized as wet and dry weather conditions, respectively. The "wet-weather" culms were harvested during the comparatively hot, rainy-season months of May, June, and July. The "dry-weather" culms were harvested toward the end of the cool, dry season, from February to April.

TABLE 7.—*Powder-post beetle infestation and starch concentration in the wood in 1-year-old culms of Bambusa vulgaris immediately after harvest, with reductions after clump-curing for approximately 1 month, in wet weather and in dry weather*

FRESHLY HARVESTED CULMS

Culm part	Beetle attacks in—		Iodine-starch score in—	
	Wet weather [1]	Dry weather [2]	Wet weather, total points [3]	Dry weather, total points [3]
	Number	*Number*	*Number*	*Number*
Base	195	493	28	21
Middle	270	680	28	31
Top	296	325	22	28
Total	761	1, 498	78	80

REDUCTION BY CLUMP CURING

Culm part	Wet weather	Dry weather	Wet weather	Dry weather
	Percent	*Percent*	*Percent*	*Percent*
Base	77. 4	13. 4	75. 0	9. 5
Middle	94. 1	81. 6	35. 7	48. 4
Top	96. 3	91. 1	45. 5	53. 6
Weighted average	90. 7	61. 2	52. 6	40. 0

[1] Weighted average per 20 test pieces equally representing 5 culms harvested from separate clumps at end of curing periods averaging 13.4±2.5 rainy days, 8.99±3.46 inches in rainfall, and 78.6°±0.3° F. in daily mean temperature.

[2] Per 40 test pieces equally representing 5 culms harvested from separate clumps at end of curing periods averaging 7.0±3.7 rainy days, 2.03±2.42 inches in rainfall, and 75.9°±1.5° F. in daily mean temperature.

[3] Per 5 samples equally representing culms mentioned in footnotes 1 and 2.

It is evident from the data given in table 7 that beetle infestation in the clump-cured bamboo culms was materially less than in the freshly harvested culms. The reduction in infestation was greater in wet, hot weather than when the weather was dry and comparatively cool. This was to be expected, since starch depletion in living wood depends, to

a certain extent, on a continuation of respiration after harvest and is accelerated by high temperatures (*9, p. 25*). The culms clump-cured during wet, hot weather remained alive longer than those cut during dry weather; for this reason, they not only used up more of their starch by natural living processes, but also lost it more quickly and uniformly because these processes were speeded up by the higher prevailing temperature.

In an investigation of curing methods, White and Ferrer reported that 5-foot sections of 1-year-old culms of *Bambusa vulgaris* clump-cured for 2 months during dry weather became heavily infested in subsequent open-shed storage. They also reported that similar sections from the same lot kept in insect-tight boxes for 6 months or longer remained uninfested after removal (*26*). This clump curing was carried out during December and January, when the monthly rainfall averaged 2.57 inches and the temperature 75.6° F., conditions similar to those that prevailed when the previously mentioned dry-weather culms were clump-cured. While no note was made at the beginning as to the reaction of the culms in either lot to the iodine spot test for starch, the authors reported that the sections when taken from the boxes reacted weakly to this test. In this case it is probable that the culms were not entirely cured when brought from the field and hence were still somewhat green when cut into sections and placed in the boxes where respiration had an opportunity to continue. This would account for both the reported heavy infestation of the check or unprotected sections and the apparent depletion of starch in the protected ones.

The experiments here reported show that for best results clump curing should be carried out in moist, warm weather when the culms are most likely to remain alive for a month or more before being removed from the field. If the base of the culms is kept from touching the ground, there will be little trouble from sap stain.

Clump-and-Shed Curing.—A combination of shed curing and clump curing was tried on another highly susceptible bamboo, a thin-walled variety of *Bambusa arundinacea* (*17*). Culms in their first and second years of growth were used. From May to July one culm of each growth age was cut every 2 weeks, successively, from five clumps and allowed to clump-cure for 4 weeks, as previously described. Both culms were then trimmed and stored entire in an open shed for 8 weeks. To study the comparative effect of water curing, a similar set of culms was cut at the same time, trimmed, and immediately placed entire in a fresh-water pond where they were kept submerged for 12 weeks. Weather conditions prevailing during the curing periods closely approximated those of the "wet weather" described earlier for clump curing alone (page 22). For convenience the results of both treatments, with corresponding data on starch concentration and moisture content and specific gravity of the wood, are presented together in table 8. The results from water curing will be discussed later.

TABLE 8.—*Powder-post beetle infestation, starch concentration, moisture content, and specific gravity of the wood in 1- and 2-year-old culms of Bambusa arundinacea var. immediately after harvest, with reductions after clump-and-shed curing and after water curing*

Culm part	Beetle attacks per 40 test pieces from—		Iodine–starch score per 5 samples, total points, from—		Moisture content of wood, average, from—		Specific gravity of wood, average, from—	
	1-yr. culms	2-yr. culms	1-yr. culms	2-yr. culms	1-yr. culms [1]	2-yr. culms [1]	1-yr. culms [1]	2-yr. culms [1]
FRESHLY HARVESTED CULMS								
	Number	*Number*	*Number*	*Number*	*Percent*	*Percent*		
Base	916	664	30	30	84. 3	76. 2	0. 625	0. 641
Middle	307	322	26	28	75. 4	61. 5	. 608	. 649
Top	34	141	17	23	67. 8	61. 3	. 588	. 643
Total	1, 257	1, 127	73	81	82. 0	72. 1	. 621	. 657
REDUCTION BY CLUMP-AND-SHED CURING								
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Base	82. 3	83. 7	53. 3	73. 3	39. 5	32. 9	[2] 5. 6	3. 2
Middle	17. 3	50. 9	92. 3	64. 3	60. 4	37. 2	[2] 9. 2	[2] 1. 8
Top	26. 5	92. 9	82. 4	91. 3	68. 3	67. 4	[2] . 5	[2] 2. 2
Weighted average	64. 9	75. 5	74. 0	75. 3	44. 9	34. 4	[2] 6. 0	1. 7

Reduction By Water Curing

Base	[2] 42.0	[2] 26.2	0	0	[2] 7.4	[2] 5.5	8.3	2.9
Middle	50.2	[2] 20.8	38.5	14.3	[2] 11.9	[2] 17.9	4.5	0
Top	64.7	92.2	76.5	52.2	[2] 18.3	12.2	9.0	.5
Weighted average	[2] 16.6	[2] 9.9	31.5	19.8	[2] 8.5	[2] 8.0	7.6	2.0

[1] Weighted average of 5 samples.

[2] Increase.

It will be noted in table 8 that a combination of clump curing and shed curing reduced the number of beetle attacks in the test pieces from the 1-year culms by 64.9 percent and in those from the 2-year culms by 75.5 percent. Both reductions were statistically significant at the 1-percent level. Starch depletion was more extensive than that which took place in *Bambusa vulgaris* that was only clump-cured (table 7). Reduction in moisture content and increase in specific gravity of the wood also were considerable, particularly in the first-year stock. With a few exceptions the same was true in the base, middle, and top parts of the culms. There seems to be little doubt that the additional curing time in the shed was beneficial.

From the standpoint alone of improving the quality of the wood it would seem well in actual practice to shed-cure the culms thoroughly after they have been clump-cured. Also, during this time the tendency of any parts to be infested because of possible uneven clump curing will become evident and such parts can then be discarded and destroyed.

Water curing

The curing of various woods by placing them in water has been used in many parts of the world to reduce their susceptibility to boring insects and has long been employed with bamboo in India where large quantities are grown commercially (*4, pp. 31–32; 24, v. 1, p. 375*). In early experiments at the Federal Experiment Station, Mayaguez, P. R., reductions of from 80 to 90 percent in powder-post beetle infestation were obtained by soaking small pieces of *Bambusa vulgaris* in fresh water or in salt water for 6 weeks (*20, pp. 35–36*). A reduction of 94 percent followed the placing of whole culms in a fresh water pond for 8 weeks (fig. 7), but since the culms were not entirely submerged they sprouted extensively, and the wood was stained and when dry it tended to be light in weight and brittle (*21, pp. 33–35*). However, water soaking offers a convenient means of preventing infestation in bamboo where such defects would be relatively unimportant.

Submersion.—In the foregoing section mention was made of keeping 1-year-old and 2-year-old culms of a thin-walled variety of *Bambusa arundinacea* under water for 12 weeks. The object of this test was to study the effects of submersion on the quality of the wood as well as on subsequent powder-post beetle infestation. The results are given in the last section of table 8.

From the information contained in table 8 it is obvious that this treatment was ineffective in preventing beetle attack in this species of bamboo. Instead of bringing about a reduction it actually resulted in an increase in infestation of roughly 17 percent in the 1-year-old and 10 percent in the 2-year-old culms. Starch concentration was somewhat reduced, though more in the former than in the latter. As might be expected of wood soaked in water, the moisture content was increased and the density decreased. The effect of this water treatment appeared to be localized in different parts of the culm. From reduction in starch concentration, the top part of the culms of both ages benefited the most and the base not at all. Changes in moisture and specific gravity in these parts were mostly small.

When taken from the water all of the culms were still alive and green, except at the cut ends. These extremities, particularly the top-

FIGURE 7.—Bamboo culms water-curing in a fresh-water pond.

most internodes, gave off a persistent foul odor, but this odor was absent from the middle internodes. Although resistance to beetle attack was not increased, complete submersion prevented shoot growth and appeared to reduce somewhat the tendency of the wood to become light in weight and brittle on drying. All but the internodes in the middle third of the culms were badly sap-stained.

CLUMP CURING AND SUBMERSION.—A test was made with the same species and ages to determine whether it would be possible to improve powder-post beetle control by clump-curing for 4 weeks previous to submersion in water. This preliminary clump-curing treatment reduced the starch concentration by one-third in the culms of both ages and the infestation by 89 percent in the first year but by only 19 percent in the second. The moisture content of the wood at time of exposure was also reduced in both ages, but the density was only slightly increased in the first-year stock and practically unchanged in the second. At the end of 12 weeks under water the culms gave off a disagreeable odor, stronger than that noted in the previous test, and some of the middle internodes contained water. Otherwise, the wood was the same as that in the previous test. Judging from the reaction of the beetles, clump curing applied before water curing would improve control. However, with the variety of bamboo used,

the combination of clump and shed curing was much more satisfactory and would be more practicable under ordinary circumstances (*17*).

Working with 1- to 4-year old culms of *Bambusa tuldoides* harvested during the last week of January, White, Cobin, and Seguinot Robles (*25, pp. 265–266*) obtained generally poor control by water-curing culms by submergence up to 27.5 weeks and by clump-curing for 2 weeks followed by submergence for 19 weeks. However, the results from clump-and-shed-curing this species were somewhat similar to those obtained with *B. arundinacea* var.

Chemical Treatments

The main problem involved in the control of the bamboo powder-post beetle is to prevent the first borings that the adults make while in search of suitable places in which to lay their eggs. As previously pointed out, this exploratory habit of the beetle is often sufficiently damaging by itself to ruin a piece of bamboo for most uses. Numerous internal and external applications of chemical treatments have been tried, but such control was found to be complicated because the adult beetles do not always swallow the wood they bite loose, and thus may avoid any poisons encountered on or in it (*23, pp. 82–83*). For this reason few chemicals, except the strong stomach poisons or long-lasting contact poisons, have been effective.

The chemicals used in the studies described below are more or less poisonous to the skin and eyes or internally. Some are inflammable. Care should be exercised in their handling and use, and precautions should be taken to see that containers of such materials do not fall into the hands of children or irresponsible persons.

Internal applications

SAP-STREAM INJECTION.—In the present work, internal treatments were applied by means of sap-stream injection. This treatment takes advantage of the natural forces of transpiration to carry the chemicals in the sap stream of the vascular system to all parts of the culm. The method mostly employed was what is called "stepping." The base of a culm, immediately after it had been cut, was placed in a container holding a water solution of the chemical to be applied, after the manner used on small trees (*2, p. 2*). During treatment the severed culm with all its leaves and branches attached was maintained upright in the clump by tying it to adjacent culms.

A dosage of 1 liter of solution was applied per cubic foot of culm, which was about the amount needed for the average-size first-year culm of *Bambusa vulgaris* used. For holding this quantity of solution in contact with the cut base, a bag made of discarded automobile tire inner tubing slipped over the end of the culm was found to serve better than an open jar or other container (see fig. 8). Such a bag could be easily and quickly attached and sealed around the culm to prevent dilution by the entrance of rain water. However, the base of the culm could not be rested on the ground but had to be suspended and properly anchored to prevent puncturing the bag and loss of solution. During dry, windy weather most solutions were taken up in 24 hours or less; under any condition none needed more than a week. However, to allow

time for diffusion of the chemicals throughout the wood the culms were left in the field and were not utilized for several weeks afterward. On account of the labor involved, this method of culm injection would be practicable only where relatively few culms are to be treated.

FIGURE 8.—The rubber bags here shown held chemical solutions applied to bamboo culms by the "stepping" method of sap-stream injection. The bottom of each bag was closed with rubber cement and wire; the top was held to the culm by wire and sealed with tape. As the solution was absorbed the lower part of the bag was drawn up and held in place by a heavy rubber band.

Introducing solutions into the sap stream through the inside of the internodes of hollow culms was tried as a possible means of avoiding the inconvenience of anchoring the culm. Without felling the culm, three 1-inch holes were bored at an angle of about 45° equidistant

around the perimeter and about 2 inches above the lowest node not having roots. Sufficient of the solution to be applied was poured inside to cover the septum to a depth of about 1 inch. The vascular tissue of the culm wall nearest the septum was then cut into for about ¼ inch with a narrow chisel inserted through these holes, care being taken not to puncture the septum while making the cut as continuous as possible all the way around. After the holes had been plugged with corks, the remainder of the solution was introduced through another hole bored in the top of the internode, and this hole was closed tightly to prevent loss of solution by evaporation. It sometimes happened that the septum at the bottom of the internode selected already had a hole in it from natural causes. In this case the internode next above was used.

Sap-stream injection by this internodal method was accomplished in about half the length of time needed for the stepping method. However, distribution of the chemical throughout the culm was inferior both longitudinally and laterally, principally because of the impossibility of severing a sufficient number of vessels on the inside of the internode. In wet weather the internode bled a great deal, sometimes sufficiently to force out the corks and waste the solution. Also the culm often cracked or split when twisted by the wind, because the base was weakened by the holes through which this treatment was applied. With modifications this method possibly could be adapted to felled culms, but in its present form it was considered impracticable for general use.

Copper Sulfate.—Many chemicals that were thought possibly to be effective in poisoning the wood were injected by the stepping method, but only one, copper sulfate, was found to be at all satisfactory; the others proved to be either ineffective or too poisonous for ordinary use (*22, pp. 110–117; 23, pp. 78–82*). Copper sulfate changed the natural color of the wood to a chrome green, which might not be considered objectionable in bamboo intended for use in the manufacture of some kinds of articles. It also had a slight tendency to corrode hardware coming in contact with the wood. However, the control produced by copper sulfate, an average of 93 percent in two tests, can be considered commercially good.

On account of the possible bearing on sap-stream injection of bamboo in general, it is of interest to examine briefly the conditions under which these tests with copper sulfate were made and the effect of these conditions on the results. They were carried out at the same time and in the same clumps as the clump-curing experiments reported in table 7. It will be recalled that one test was made under what were characterized as wet-weather conditions and the other during comparatively dry weather. For the copper sulfate injections a nearly saturated solution, 333.21 grams per liter, was used each time. The percentage reduction in infestation obtained in both kinds of weather is shown in table 9.

TABLE 9.—*Powder-post beetle infestation and starch concentration in the wood in 1-year-old culms of Bambusa vulgaris immediately after harvest, with reductions after sap-stream injection with copper sulfate, in wet weather and in dry weather*

FRESHLY HARVESTED CULMS

Culm part	Beetle attacks in—		Iodine-starch score in—	
	Wet weather [1]	Dry weather [2]	Wet weather, total points [3]	Dry weather, total points [3]
	Number	*Number*	*Number*	*Number*
Base	195	493	28	21
Middle	270	680	28	31
Top	296	325	22	28
Total	761	1, 498	78	80

REDUCTION BY COPPER SULFATE INJECTION

Culm part	Wet weather	Dry weather	Wet weather	Dry weather
	Percent	*Percent*	*Percent*	*Percent*
Base	98. 0	94. 9	[4] 7. 1	[4] 42. 9
Middle	93. 7	95. 7	[4] 7. 1	9. 7
Top	72. 0	98. 5	[4] 27. 3	7. 1
Weighted average	86. 3	96. 1	[4] 12. 8	[4] 5. 0

[1] Weighted average per 20 test pieces equally representing 5 culms harvested from separate clumps at end of injection periods of approximately 1 month averaging 13.4±2.5 rainy days, 8.99±3.46 inches in rainfall, and 78.6°±0.3° F. in daily mean temperature.

[2] Per 40 test pieces equally representing 5 culms harvested from separate clumps at end of injection periods of approximately 1 month averaging 7.0±3.7 rainy days, 2.03±2.42 inches in rainfall, and 75.9°±1.5° F.

[3] Per 5 samples equally representing culms mentioned in footnotes 1 and 2.

[4] Increase.

It will be seen that distribution of the chemical throughout the culm, as indicated by the reduction in number of beetle attacks, was much more uniform in dry weather than in wet. This was also shown by spot tests for copper made on the wood from various parts of the culms. During wet weather the copper sulfate was concentrated in the lower part of the culms; apparently they were killed before much of the chemical could be carried to the top by transpiration. The reverse was true in the culms treated during dry weather, when absorption was more rapid.

The iodine-starch score seemed to be markedly affected by copper sulfate; instead of being reduced as in clump curing (table 7), it was increased, though less on the average in dry weather than in wet. Not shown in table 9 is the fact that the base and middle parts of the injected culms received the highest score under both conditions.

Since these parts also contained the highest concentration of copper sulfate, it is possible that the blue-green color left by that chemical increased the intensity of the iodine color reaction to an abnormal extent and thus caused a higher reading over that for freshly harvested culms. In any event, the apparent increase in starch in the injected wood had little or no effect on infestation; control was still dependent on thoroughness of distribution of the copper sulfate. In other words, regardless of how much starch was indicated, the wood was not attacked much so long as it contained copper sulfate.

From these tests it would appear that dry-weather conditions, which are not favorable for clump curing and starch depletion, are best for treating bamboo culms with chemicals by the stepping method of sap-stream injection. Maximum control could be expected with copper sulfate under such conditions because of quick absorption and thorough distribution of the chemical throughout the wood.

Chemicals that could be applied to the soil in sufficient amounts to make the wood poisonous to the beetle by absorption through the roots were not investigated. However, a study of such absorption, especially of the newer insecticides, should yield results of fundamental importance and wide application.

Chemicals to Deplete Starch.—Hydrochloric acid of 2-percent strength was applied by the stepping method of sap-stream injection to see if it would make the wood unattractive to the beetle by hydrolyzing the starch in the culm. This test was made along with the dry-weather, clump-curing tests and copper sulfate injection just described. However, in spite of favorable conditions for absorption, starch reduction was only half that which followed clump curing. Reduction in beetle infestation, which averaged 55 percent, was more uniform throughout the culm but only slightly better than that following clump curing and only about two-thirds of that produced by copper sulfate under the same conditions. Other serious disadvantages of the hydrochloric acid treatment were that it made the wood brittle and seriously weakened the contact of the fibers with the surrounding tissue (*23, pp. 78–82*).

A few growth-modifying substances known to cause a physiological depletion of starch in certain plants were tested for their possible effect on the starch content of bamboo culms. Following inconclusive results with a 1–to–500 solution of 2,4–D (2,4-dichlorophenoxyacetic acid) applied by the stepping method of sap-stream injection, further qualitative tests were made with this chemical and with indolebutyric and indoleacetic acids.[5] These were applied by the internodal injection method and by means of small wooden plugs impregnated with the chemical and inserted in holes bored into the base of the culm. All failed to reduce the concentration of starch in the wood by any amount that could be detected by the iodine spot test. Moreover, the wood of similar culms clump-cured at the same time was generally lower in starch than the wood of the treated culms.

Further search should be made among the more recently developed growth-regulating substances for compounds that can be used either directly or indirectly to deplete starch in bamboo. Since culms that have matured seed are known to be free of starch but still retain good

[5] These tests were made in cooperation with Arnaud J. Loustalot, chemist.

quality (*5, pp. 8–9*), it would seem profitable to investigate also compounds that may have a tendency to induce flowering.

Resin Impregnation.—Impregnating the wood with a synthetic resin was tested to determine the effect on susceptibility to beetle attack. In cooperation with the Puerto Rico Industrial Development Co., San Juan, P. R., and the Charles F. Orvis Co., Manchester, Vt., samples from the lower two 10-foot sections of culms of *Bambusa tulda* and *B. vulgaris* 2 years old or older were treated with liquid bakelite under pressure by a process known as "bakelite forcing." When the bakelite solidified, the character of the wood of both species was noted to be markedly changed. Although the pores were not entirely closed or the reaction to iodine materially modified, the treatment hardened the wood and imparted to it other commercially desirable qualities. In more than 4 years of continuous exposure to the beetles near large quantities of infested bamboo, none of the bakelite-impregnated samples of either species was attacked. Among the untreated samples those of *B. tulda* were entered at a few places and those of *B. vulgaris* were heavily infested. Impregnation with liquid bakelite would seem to be especially applicable in the protection of bamboo intended for use in the manufacture of small articles or certain kinds of furniture (*14, p. 36*).

External applications

A number of chemical dips and sprays were applied to small strips and rings of bamboo by Lee, Watson, and Gibbons (*20, pp. 32, 37–39*). Of these, hot creosote and a suspension of 1 pound of paris green in 5 gallons of water gave the best control, about 98 percent; but like many of the other less effective materials employed, these either adversely changed the color of the wood or made it too poisonous for general use. In the same category was the method of dipping the wood in a nearly saturated solution of copper sulfate alone and this treatment followed by dipping in a solution of sodium arsenate, 1 pound in 5 gallons of water.

Among other chemicals tried that did not have the foregoing objections, dinitro-ortho-cyclohexyl-phenol—1 percent in kerosene applied as a 10-second dip to rings of first-year *Bambusa vulgaris*—was the only one that kept beetle infestation at a low level over a period of 6 months; the average control produced was 90 percent (*16, p. 65*). Applied by brushing on half-culm sections none of these chemicals afforded effective protection against the beetle.

DDT.—As previously pointed out, one of the great disadvantages of all open-curing methods is that the culms become infested before curing is complete. Therefore, a search was made for a material that would provide long-lasting protection in whole culms or at least allow curing of such culms to proceed and to produce its maximum effects without interference from beetle infestation. Such a material could then be relied upon to give equal or better protection to smaller pieces.

Three apparently promising materials in this class were given a preliminary test by brushing them on freshly harvested 1-year-old culms of *Bambusa vulgaris:* Pentachlorophenol at about 4 percent in kerosene, sodium pentachlorophenate with wettable sulfur, both at 2 percent in water as used for lyctus control in lumber (*1*), and DDT at the residual-spray strength of 5 percent in kerosene. At the end of about 2½ months, the first two of these treatments resulted in only

3 and 6 percent less internodal infestation, respectively, than that in the untreated culms, whereas DDT reduced such damage by 94 percent and left no objectionable after effects (*16*, *p. 66*). In spite of the fact that iodine spot tests showed high concentrations of starch in the wood, there were few beetle entrances in the DDT-treated culms, and these were mostly at trimmed nodes. The majority of these holes were shallow, many still containing beetles that died before they could bore more than a few millimeters into the wood.

Permanence of DDT.—To obtain within certain limits an indication of how long DDT might be effective, a more extensive test than the foregoing was made with the dipping method (*19*). DDT was used at the same 5-percent strength as before, but Diesel fuel oil having a specific gravity of 0.834 at 27° C. was used as the solvent, the dipping time was 10 minutes, and the culms, taken from 10 clumps of *Bambusa vulgaris*, were cut into 3 adjacent sections of 10 internodes each for convenience in handling (fig. 9). One-half of the number of culms used were clump-cured for 35 days before dipping to note

Figure 9.—Dipping bamboo in 5-percent solution of DDT in Diesel fuel oil for protection against infestation by the bamboo powder-post beetle.

the effect of partial drying on residual control. To make 50 gallons of dipping solution required 17.5 pounds of DDT and 48.5 gallons of oil, and to treat the three 10-internode sections of an average culm required about ⅕ of a gallon of solution. External examinations were made of all sections periodically every 3 months for 1 year. At the end of the first 3 months 98 percent fewer internodes were infested in both the freshly harvested and the clump-cured culms than in the undipped culms of either kind; at the end of 12 months after dipping the control of internodal infestation was 91 percent and 88 percent, respectively.

Since the penetration of the treating solution was slight, only the outside of the culms was protected by the DDT treatment. Therefore, the culm sections were split open at the end of 12 months to determine the extent of internal damage by the beetles that succeeded in passing the DDT coating. Among the untreated culms all of the internodes were infested in those that had been freshly harvested and all but about 2 percent in the clump-cured. Most of the former were riddled, whereas those that had been clump-cured were, in general, lightly damaged. However, where the DDT dip was applied 91 percent of the internodes in the freshly harvested culms and 79 percent of those in the clump-cured culms were still undamaged. Most of the damaged internodes, particularly those in the clump-cured culms, had been scored longitudinally on the inside by the beetles, some of which had entered through cracks that developed in the rind, but the majority of such pieces were still considered serviceable for certain purposes. Apparently no benefit is to be obtained from previously drying the culms, as in clump curing, before dipping in DDT.

Much internal damage could have been prevented by first splitting these hollow culms or breaking out or puncturing the septa, or partitions at the nodes, so that the solution could cover the inside as well as the outside surface. Ring sections from the culms used in the foregoing test and dipped in the same solution have remained unattacked for, now, nearly 3 years. Also, small quantities of hollow bamboo that were split open before dipping and retreated after shaping for commercial use have thus far—more than 3 years after treatment—remained immune to attack.

In contrast to the white, fine-grained crystallization left by the kerosene solution used in the preliminary tests, that from DDT in fuel oil was nearly translucent and tended to form slender, branching threads having the general appearance of fine tree roots. Not easily dislodged by rubbing or brushing, it was still visible on many culm sections at the end of 12 months. Neither this residue nor the Diesel oil solvent appeared to stain or otherwise adversely affect the quality of the wood. However, no gluing tests were made, and it is possible that DDT in Diesel fuel oil may affect gluing quality in wood intended for certain uses. Although it was not tested, dipping the culms in micro-fine suspensions of DDT in water should obviate damage to the gluing quality of the wood and afford practically the same protection from the beetle.

DDT was not tried on solid or semisolid culms of bamboo, but the small amount of infestation thus far noted in such species would doubtless be controlled by an application immediately after harvest,

followed by a second dipping from 3 to 6 months later. This latter additional treatment should be beneficial on hollow culms also, since, as already noted, an appreciable amount of internal damage in such culms has been caused by beetles entering through cracks that developed after the first treatment.

Although some of the newer materials and others as they are developed may prove to be more effective in controlling the bamboo powder-post beetle, DDT is the most satisfactory insecticide yet tried. Perhaps the greatest advantage of DDT is that it can be conveniently used on freshly harvested culms to protect them from infestation while the wood is naturally increasing in beetle resistance through adequate curing. Its demonstrated residual action is of sufficient permanance to carry the culms well through this critical period, when liability to infestation is greatest. DDT does not adversely affect the color or usability of the wood and, therefore, can be employed to protect both small and large articles after, as well as during, manufacture.

SUMMARY AND RECOMMENDATIONS

Studies are recorded of factors that influence the susceptibility of harvested bamboo to attack by the bamboo powder-post beetle (*Dinoderus minutus*) and of measures that might be used to reduce or prevent damage. Standardized methods of procedure are described for conducting tests of susceptibility and control measures.

The presence of starch in the wood, as estimated quantitatively from variations in color intensity produced by the iodine spot test, was the most important factor influencing susceptibility. Next in importance were: The species and variety of bamboo, the age of the culm at harvest, the time of harvest, and the physical properties of the wood.

Culms of the standard test species, *Bambusa vulgaris*, were found to contain the most starch and, with few exceptions, to be the most extensively attacked. The relative susceptibility of 1-year-old culms of 11 other species varied from 44.2 percent in *B. vulgaris vittata* to 0.3 percent in *B. textilis*. With minor variations, the base was the most susceptible part of the culm and the middle was more susceptible than the top.

Susceptibility studies of 1- to 5-year-old culms indicated that much damage by the bamboo powder-post beetle can be avoided in *Bambusa vulgaris* by harvesting culms in their third year of growth or older; in *B. tulda* and *B. tuldoides*, by harvesting in the second year or older; and in *Dendrocalamus strictus* and *Sinocalamus oldhami*, by harvesting culms during their first 3 years of growth.

Harvesting in the late summer and fall months—August to December—resulted in less infestation than harvesting during the late winter and spring months—February to May. From the data available, it may be assumed that powder-post beetle infestation cannot be avoided by harvesting according to the phase of the moon.

When felled culms were clump-cured in the field, where beetle infestation is rarely observed, this method resulted in up to 90 percent control of infestation. Best results were obtained during moist, hot weather when the culms could be kept alive for a month or more, during which period most of their starch was depleted. Shed-curing the

culms for at least 8 weeks after they had been clump-cured made them even less susceptible to infestation.

Powder-post beetle infestation was reduced by 94 percent by placing the freshly harvested culms in water for 8 weeks. This treatment, however, stained the wood and made it light in weight and brittle. Submerging culms completely for 12 weeks did not give effective results. Clump curing before submerging helped to avoid beetle infestation, but was not so satisfactory as clump-and-shed curing.

The stepping and internodal methods of injecting water solutions of poisons into the sap stream of bamboo culms are described. Injecting copper sulfate by the stepping method gave an average of 93 percent control in two tests. Because of more rapid and thorough absorption, better results were obtained during the late winter and spring months, when the days were bright and windy with little rainfall, than during wet weather.

Hydrochloric acid injected into the sap stream failed to hydrolyze the starch in the culms and seriously reduced the strength of the wood. The growth-modifying substances tried also failed to reduce starch concentration. Substances that induce flowering should be investigated, since culms that have matured seed are known to be free of starch.

Impregnation with a synthetic resin made bamboo wood immune to attack and imparted to it other desirable qualities.

External applications of a number of chemicals, including pentachlorophenol and sodium pentachlorophenate with sulfur, used for lyctus control in lumber, were ineffective and undesirably changed the color or other quality of the wood or created a poison hazard.

DDT, 5-percent in kerosene, brushed on freshly harvested culms, reduced internodal infestation by 94 percent at 2½ months after application without ill effect to the wood or to persons who handled or used it.

DDT at 5-percent in Diesel fuel oil applied as a 10-minute dip reduced infestation by 98 percent at 3 months and 91 percent at 12 months after application. The DDT-Diesel oil residue was still toxic to the bamboo powder-post beetle at the end of nearly 3 years.

Clump-curing the culms before dipping in DDT did not improve control, but splitting them or breaking out the partitions at the nodes helped to prevent beetle infestation. To keep the residual coating of this chemical intact and thereby prolong its effectiveness, one should avoid handling the treated culms more than is necessary for ordinary inspection during storage.

A second dipping at 3 months is recommended where splitting occurs and for wood in the process of manufacture and solid or semisolid culms. Water suspensions of DDT, preferably the micronized forms, should be used where gluing difficulties may be created by oil solutions.

Strict sanitation measures should be followed to reduce the beetle population. It is also recommended that the wettable forms of DDT be liberally sprayed or brushed on curing racks, the inside of curing sheds and workrooms, and in every other place where finished articles made of bamboo, as well as those in the process of manufacture, may be stored.

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U. S. GOVERNMENT PRINTING OFFICE: 1950